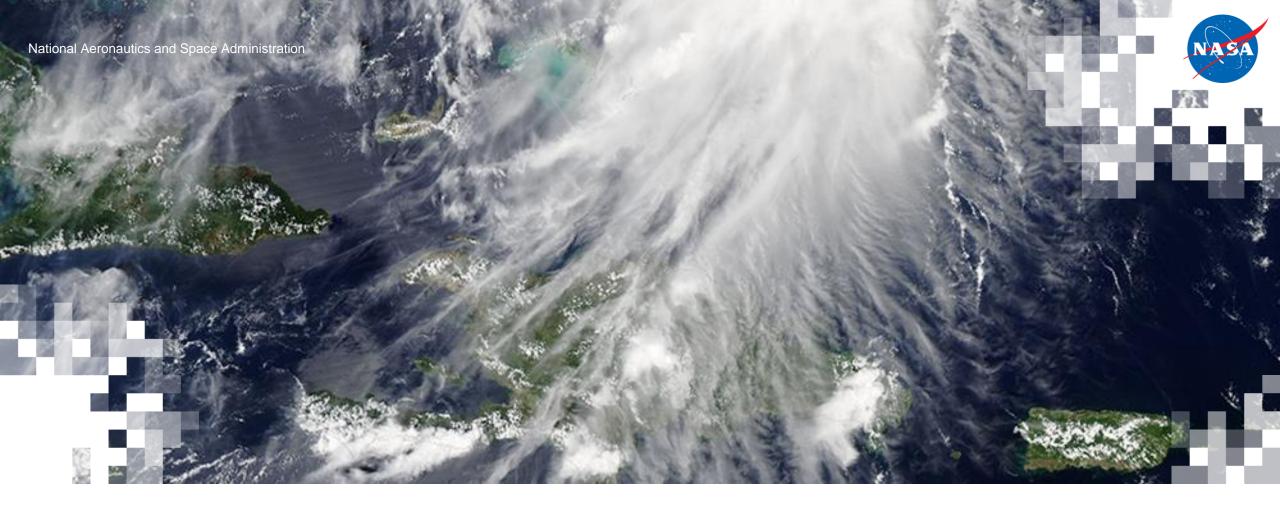




# Satellite Observations for Analyzing Natural Hazards on Small Island Nations

Assessing Pre- Storm Conditions and Post-Storm Impacts Erika Podest, Amita Mehta, Sean McCartney, John Englander August 18, 2021





# Introduction

Erika Podest, NASA Jet Propulsion Laboratory

### **Training Objectives**



- Identify applications of passive and active remote sensing data for flooding, storm impacts, landslides, and sea level rise
- Perform an analysis pre- and post-storm event for a region of interest
- Assess the landslide hazard for a region of interest prior-to and during an event
- Interpret satellite-derived products for characterizing sea level rise on a regional scale



# **Training Outline**



#### Assessing Pre- and Post-Storm Impacts

August 18, 2021



https://phys.org/news/2019-12-philippines-homes.html

Assessing Sea Level Rise at the Regional to Local Scale

August 24, 2021



https://e360.yale.edu/features/rising waters how fast and how far will sea levels rise

Assessing Landslide Hazards

August 26, 2021



https://ttweathercenter.com/severe-weather/landslides/



#### **Outline for Session 1**



- About ARSET
- Rising Waters: Four Time Horizons
- Small Island Nations: Natural disasters and impacts
- Monitoring storms using remote sensing and Earth system model data
- Monitoring during- and post- flood conditions using SAR data
- Assessing impacts of storms and floods on population and cropland



#### **About ARSET**

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- ARSET provides accessible, relevant, and cost-free training on remote sensing satellites, sensors, methods, and tools.
- Our trainings are:
  - Online and \*in-person
  - Open to anyone
  - Live, instructor-led or self-guided
  - Tailored to those with a range of experience in remote sensing, from introductory to advanced

- ARSET offers trainings for:
  - Disasters
  - Health & Air Quality
  - Land Management
  - Water Resources











For more information, visit appliedsciences.nasa.gov/arset



<sup>\*</sup>ARSET is not currently offering in-person trainings due to the COVID-19 pandemic.





# Rising Waters: 4 Time Horizons

John Englander, Executive Director of the Caribbean Center for Rising Seas









# Data





# Data

# Knowledge







# Data

# Knowledge

Safety







### **Coastal Flooding**

77

- 1.Storms
- 2. Rain
- 3. Runoff
- 4. Extreme Tides
- 5. Rising Sea Level
- 6. Erosion

















#### **4 Time Horizons**



Geologic Time ("Paleo")

10,000 year + Millennia

The Observational Record

1850 - Present Centuries

"Today & Tomorrow"

Forecast Period:

30 days

Planning and Projections

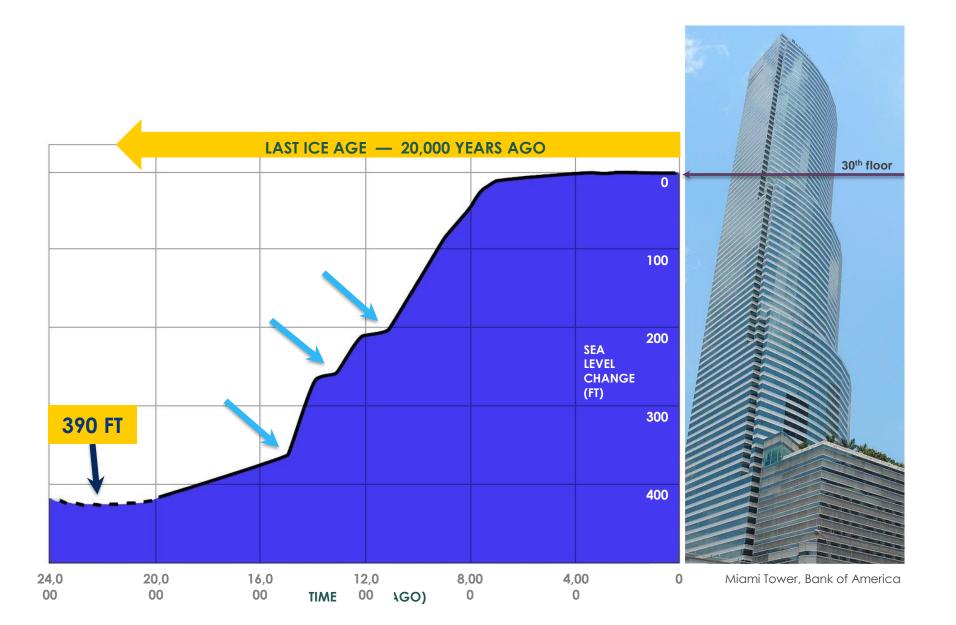
30 – 100 years



#### Florida Sea Level

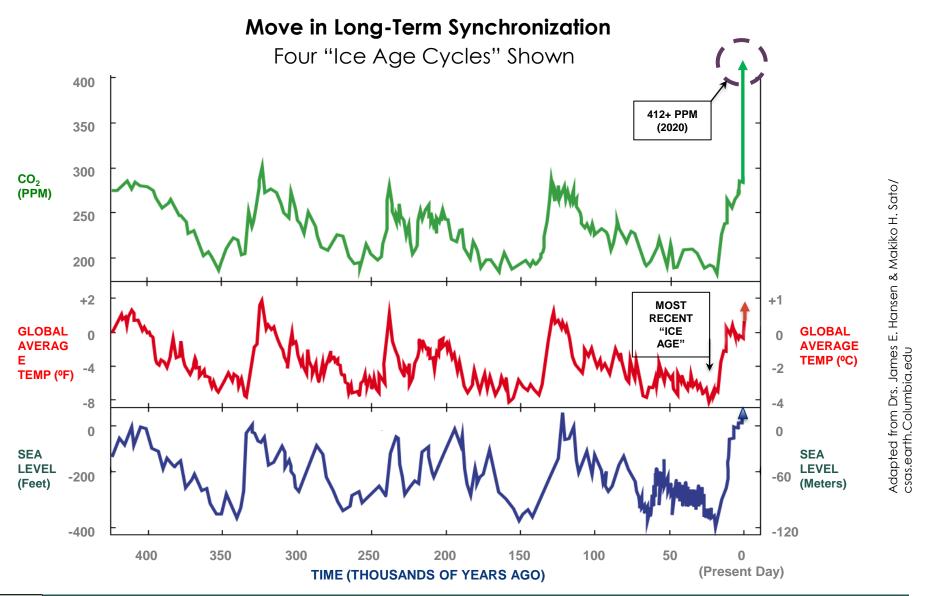


# Sea Level Since Last Ice Age



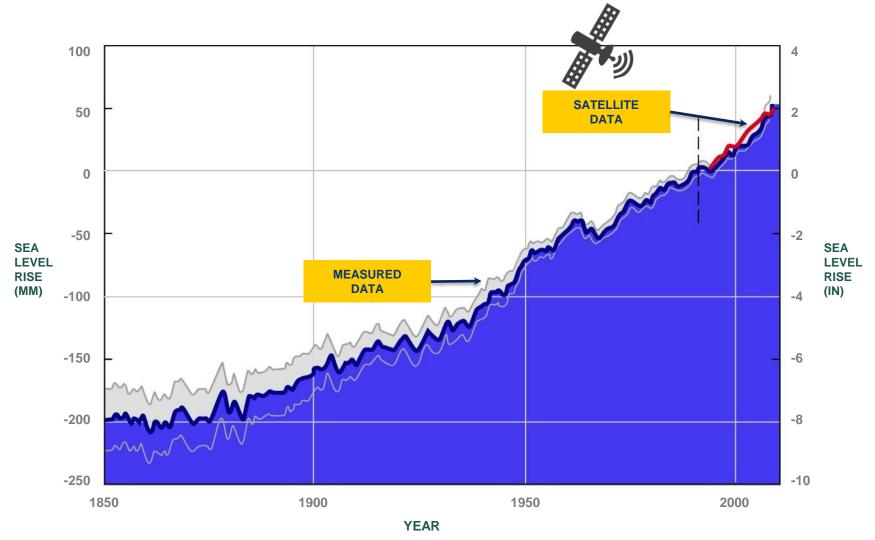


### Carbon Dioxide (CO<sub>2</sub>), Temperature, & Sea Level



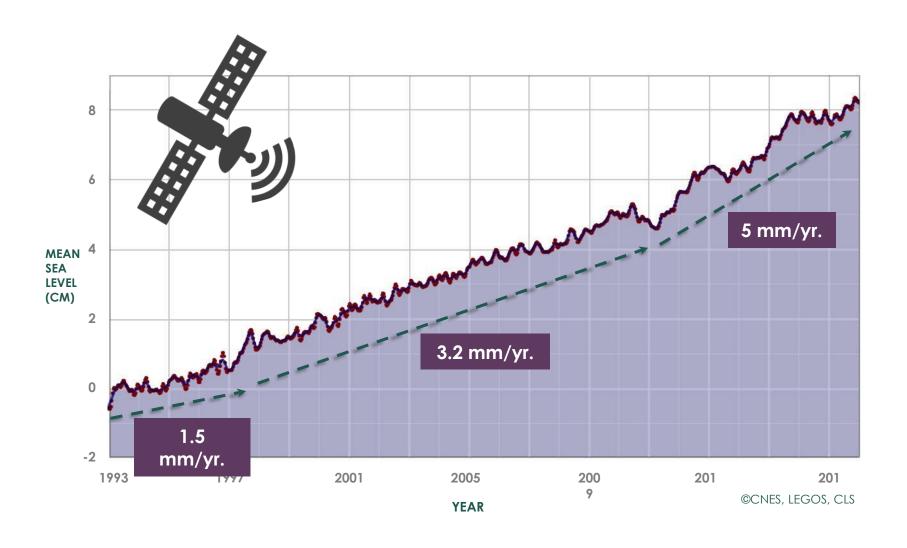
# 20<sup>TH</sup> Century Sea Level Rise



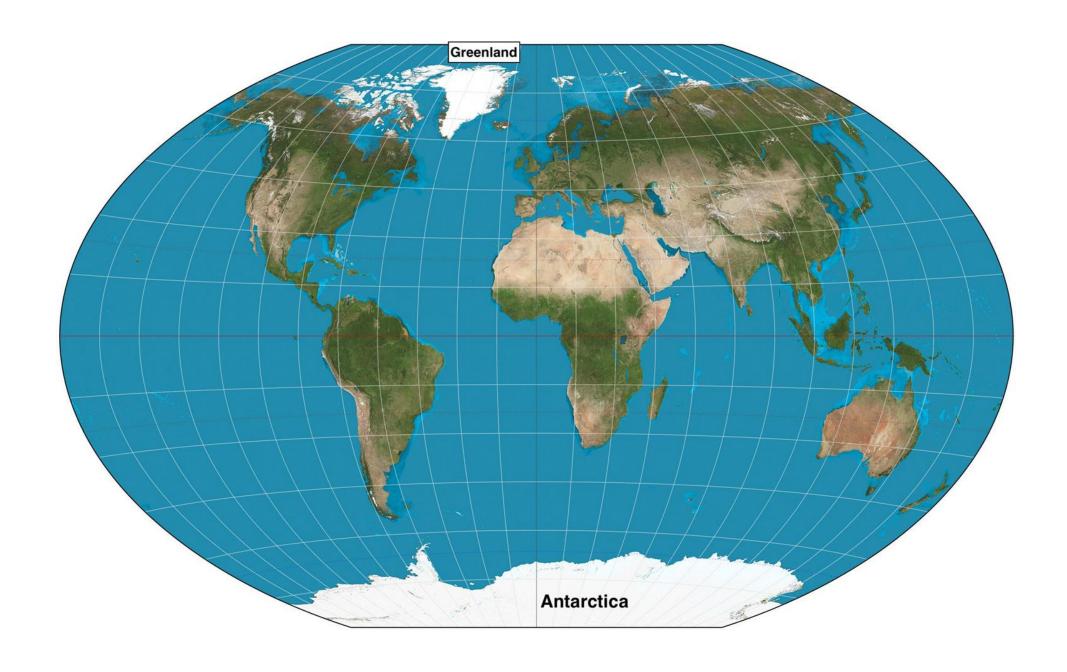


### Rate Is Accelerating









# Greenland – Approximate Size Comparison















# **FUTURE**







# 30 Years?







30 Years?

100 Years?





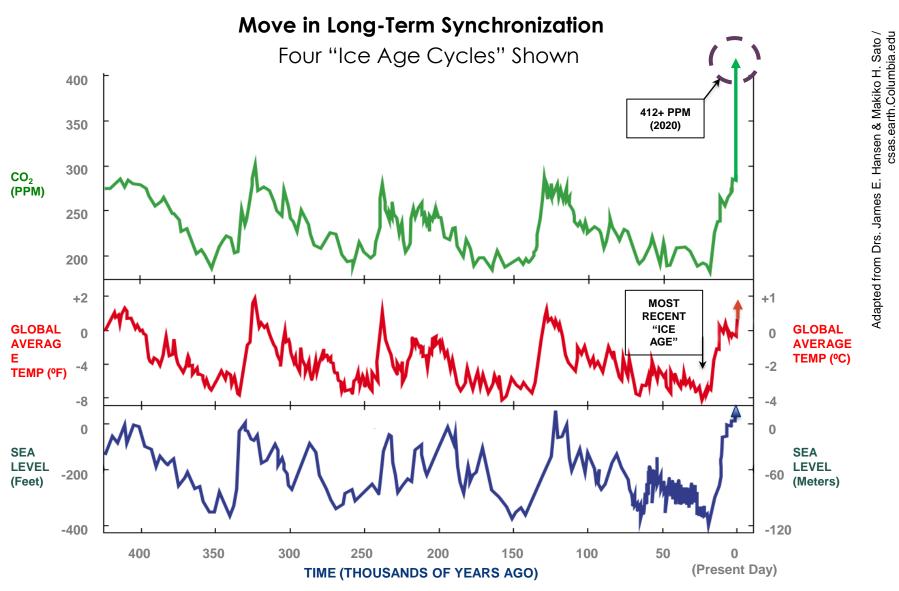
# Data

# Knowledge

Safety



### Carbon Dioxide (CO<sub>2</sub>), Temperature, & Sea Level



### We Must Rise With the Tide





#### Contact





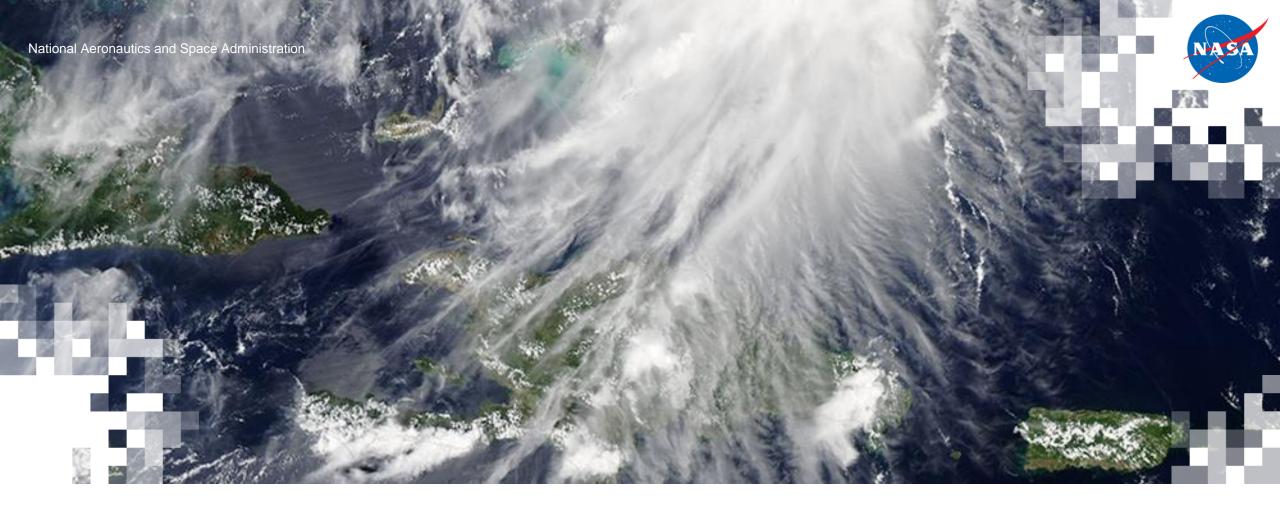






- www.johnenglander.net
- Blog and newsletter
- Twitter: @johnenglander
- LinkedIn
- Facebook







# Island Nations: Natural Disasters and Impacts

Amita Mehta, NASA Goddard Space Flight Center

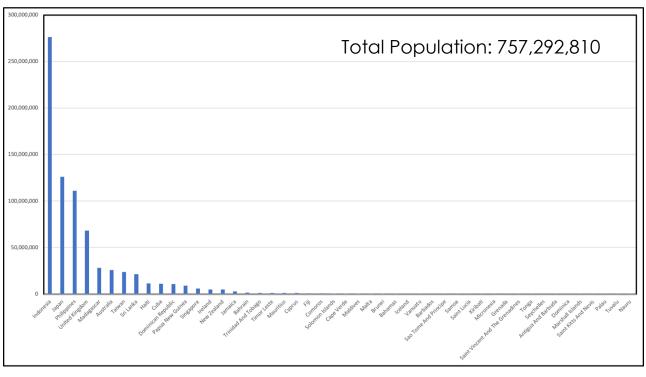
## **Island Nations**

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- There are roughly 50 island nations throughout the world's oceans.
- The area of these island nations varies from 1,904,569 km<sup>2</sup> for Indonesia to 181 km<sup>2</sup> for the Marshall Islands.
- The United Nations lists 58 member and non-member Small Island Developing States.

(http://unohrlls.org/about-sids/country-profiles/

#### Population of Island Nations in 2021:



https://worldpopulationreview.com/country-rankings/island-countries



## **Island Nations**

# m

#### Atlantic Ocean



#### Mediterranean Sea



#### Caribbean Sea



https://www.worldatlas.com/geography/island-countries-of-the-world.html#h 91779954414171622193661560



## **Island Nations**

#### Indian Ocean



#### Pacific Ocean











#### **Disasters in Small Island Nations**

- Major disasters in many of the islands include:
  - Cyclones/Hurricanes/Typhoons
  - Torrential Rain
  - Floods and Landslides
  - Storm Surge
  - Earthquakes
  - Tsunamis
  - Volcanic Activity



The impact of Hurricane Matthew in Haiti underscores the disaster risks faced by Small Island Developing States.

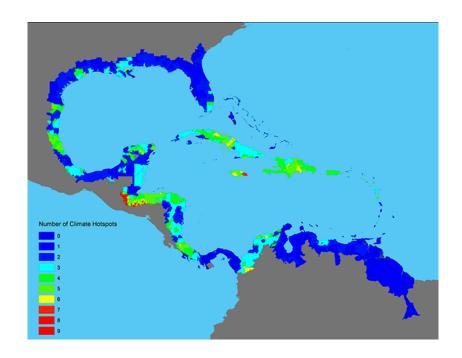
https://www.oas.org/pgdm/document/BITC/papers/gibbs/gibbs\_02.htm

https://www.undrr.org/news/risks-small-island-developing-states-spotlighted



#### Disasters in Small Island Nations

Islands are the most vulnerable to climate change and related disasters.



Gulf of Mexico/Caribbean number of extreme climate hotspots, by administrative unit. Blues are low number; greens moderate; yellow to red show progressively more. (Courtesy CIESIN)

https://news.climate.columbia.edu/2010/12/16/the-caribbeans-growing-disaster-hotspots/



An overhead view of Ejit in the Marshall Islands, center, where rising sea levels are already an inescapable part of daily life.

https://www.nationalgeographic.com/environment/article/rising-seas-force-marshall-islands-relocate-elevate-artificial-islands



### Disasters In Latin America and Caribbean Islands

https://reliefweb.int/report/world/natural-disasters-latin-america-and-caribbean-2000-2019

## Total of 1,205 disasters between 2000 and 2019

- 548 Floods
- 330 Storms
- 75 Earthquakes
- 74 Droughts
- 66 Landslides
- 24 Wildfires
- 50 Extreme Temperatures
- 38 Volcanic Events

- Floods and storms are the most common disasters.
- Since 2000, 12 floods have caused damages worth \$1 billion USD.
- There is an average occurrence of 17 hurricanes per year with 23 Category 5 hurricanes.



## Impact of Storms on Island Nations

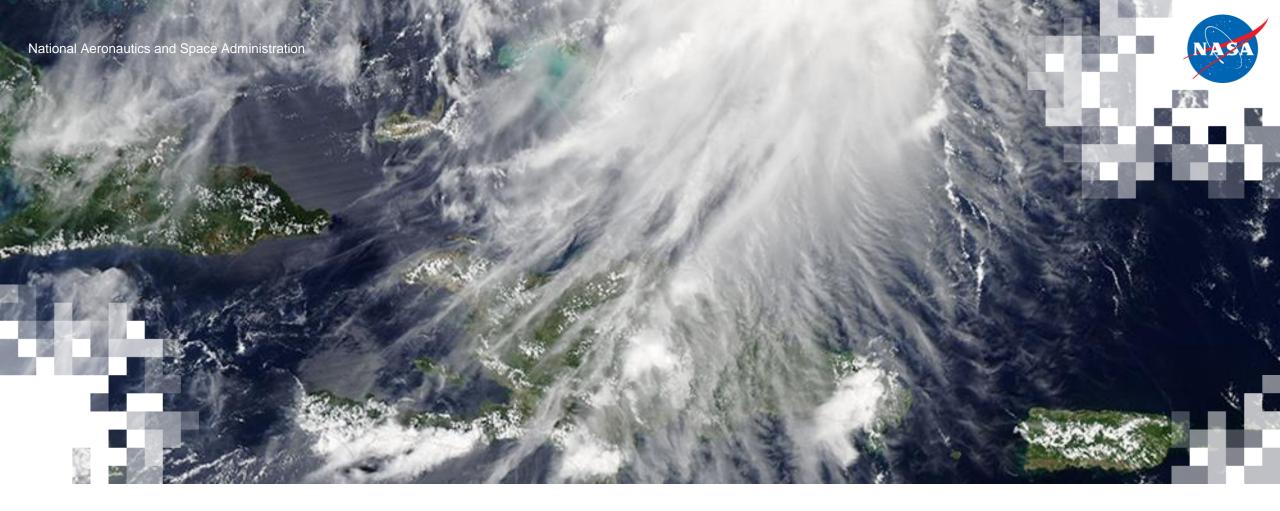
https://scied.ucar.edu/learning-zone/storms/hurricane-damage

- Precipitation, winds, and storm surge associated with hurricanes, typhoons, and cyclones are the most damaging parameters that affect conditions and lives on islands.
  - Heavy rains can cause flooding and can trigger landslides in certain regions.
  - Strong winds can cause infrastructure damages.
  - Storm surge can result in coastal flooding of settlements and bring saltwater onshore.



https://public.wmo.int/en/resources/bulletin/early-warnings-of-coastal-inundation







Monitoring Storms using Remote Sensing and Earth System Model Data

Amita Mehta, NASA Goddard Space Flight Center

## **Monitoring Storm**

NASA remote sensing and Earth system model data provides continuous, large spatial coverage of storms in near-real time as well as forecasting.



NASA's Integrated Multi-satellitE Retrievals for GPM (IMERG) data were used to track the amount of rain from Hurricane Maria.



# Monitoring Storm Track, Intensity, & Rainfall

Relevant remote sensing and model data and data access:

Parameters	Data Sources	Data Access
Rainfall	IMERG	GEE  https://earthengine.google.com/ Giovanni https://giovanni.gsfc.nasa.gov/giovanni/
	GEOS-5	Weather Analysis and Prediction  https://gmao.gsfc.nasa.gov/weather_prediction/
Sea Level Pressure Winds	MERRA GEOS-5	GEE, Giovanni Weather Analysis and Prediction

IMERG: Integrated Multi-satellitE Retrievals for GPM

GEOS-5: Goddard Earth Observing System, Version 5 (GEOS-5)

MERRA: Modern-Era Retrospective analysis for Research and Applications (MERRA)

GEE: Google Earth Engine

https://appliedsciences.nasa.gov/join-mission/training/english/arset-fundamentals-remote-sensing

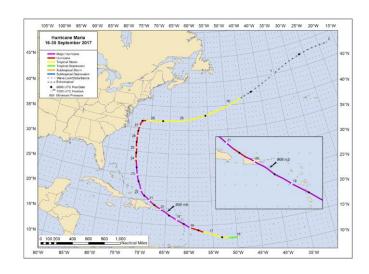


# Monitoring Storm Track, Intensity, & Rainfall



#### Case Study:

Hurricane Maria – September 16-30, 2017



https://www.nhc.noga.gov/data/tcr/AL152017 Maria.pdf

Category 4 Hurricane María made landfall in Puerto Rico on September 22, 2017.

Storm impact in Puerto Rico:

- High number of casualties
- Destruction of property, including roads & traffic lights
- Migration of thousands of residents to the U.S. mainland following the storm

https://www.climate.gov/news-features/understanding-climate/hurricane-marias-devastation-puerto-rico



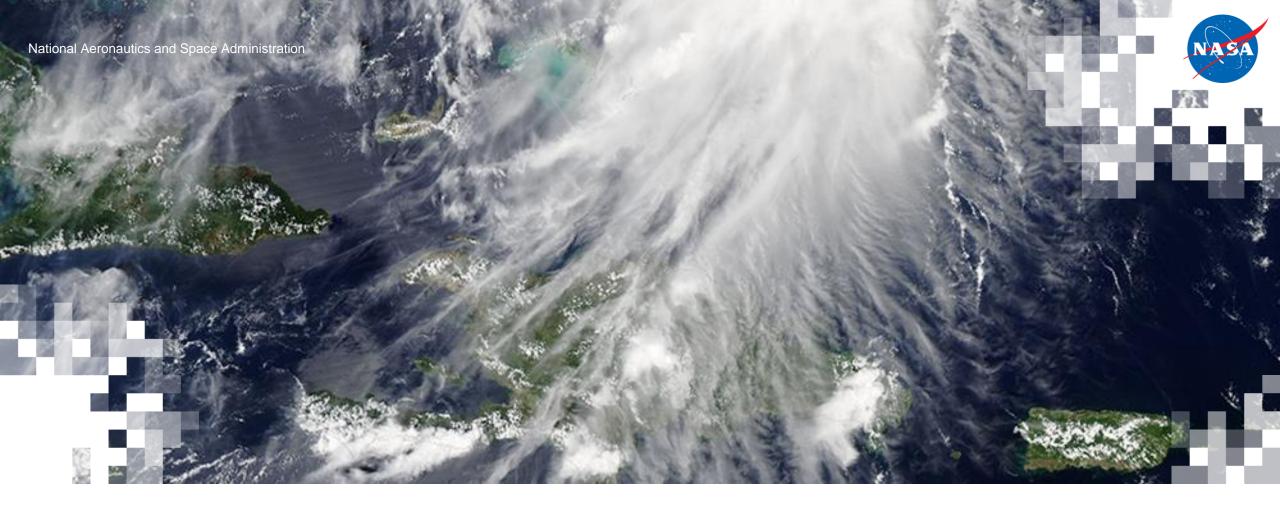




Monitoring Hurricane María: Precipitation, Winds, Sea Level Pressure

https://code.earthengine.google.com/7fe2cfb8cf7c0f12f85f8f5426f18401

Amita Mehta, NASA Goddard Space Flight Center



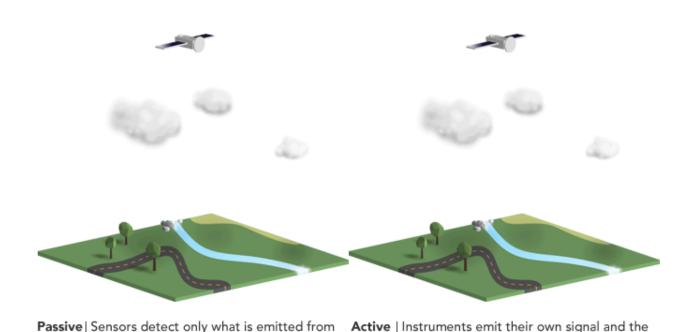


# RADAR Refresher

Erika Podest, NASA Jet Propulsion Laboratory

## **Active and Passive Remote Sensing**





sensor measures what is reflected back.

Sonar and radar are examples of active

sensors.

#### **Passive Sensors:**

- The source of radiant energy arises from natural sources
- e.g., The Sun, Earth, other "hot" bodies

#### **Active Sensors:**

- Provide their own artificial radiant energy source for illumination
- e.g., RADAR, Synthetic Aperture RADAR (SAR), LiDAR

the landscape, or reflected from another

source (e.g., light reflected from the sun).

# Advantages and Disadvantages of RADAR Remote Sensing over Optical



#### Advantages:

- Nearly all-weather capability
- Day or night capability
- Penetration through the vegetation canopy
- Penetration through the soil
- Minimal atmospheric effects
- Sensitivity to dielectric properties (liquid vs. frozen water)
- Sensitivity to structure

#### Disadvantages:

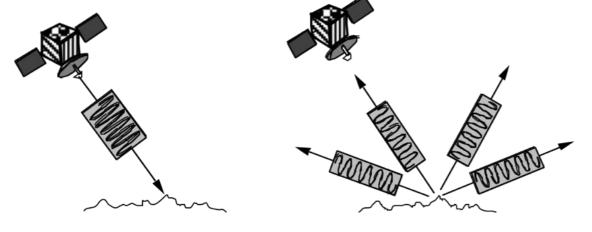
- Information content is different than optical and sometimes difficult to interpret
- Speckle effects (graininess in the image)
- Effects of topography



## Review of RADAR Image Formation

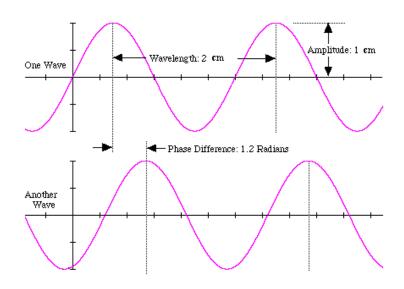
49

- RADAR can measure amplitude (the strength of the reflected echo) and phase (the position of a point in time on a waveform cycle).
- 2. RADAR can only measure the part of the echo reflected back towards the antenna (backscatter).
- 3. RADAR pulses travel at the speed of light.



RADAR TRANSMITS A PULSE

MEASURES REFLECTED ECHO (BACKSCATTER)



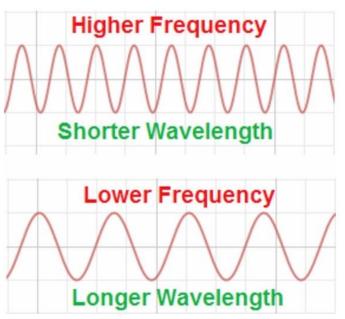
Source: ESA-ASAR Handbook



# **RADAR Parameters: Wavelength**



Wavelength = -	Speed of Light	
	Frequency	



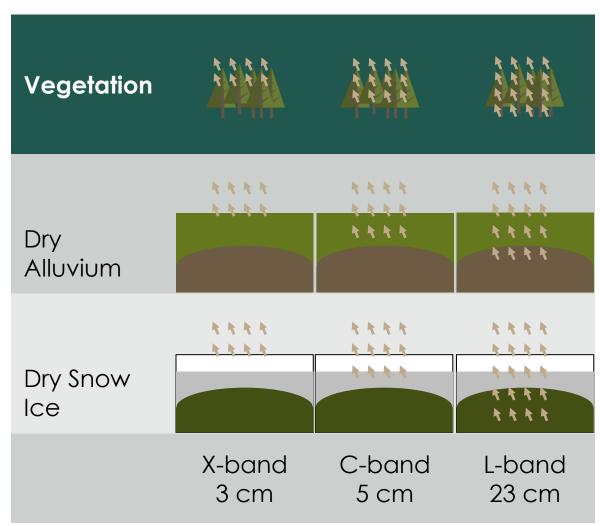
Band designation*	Wavelength (λ), cm	Frequency (ν), GH <sub>z</sub> (10 <sup>9</sup> cycles · sec <sup>-1</sup> )
Ka (0.86 cm)	0.8 to 1.1	40.0 to 26.5
К	1.1 to 1.7	26.5 to 18.0
Ku	1.7 to 2.4	18.0 to 12.5
X (3.0 cm, 3.2 cm)	2.4 to 3.8	12.5 to 8.0
C (6.0)	3.8 to 7.5	8.0 to 4.0
S	7.5 to 15.0	4.0 to 2.0
L (23.5 cm, 25 cm)	15.0 to 30.0	2.0 to 1.0
P (68 cm)	30.0 to 100.0	1.0 to 0.3

<sup>\*</sup> Wavelengths most frequently used in SAR are in parentheses.



## Penetration as a Function of Wavelength





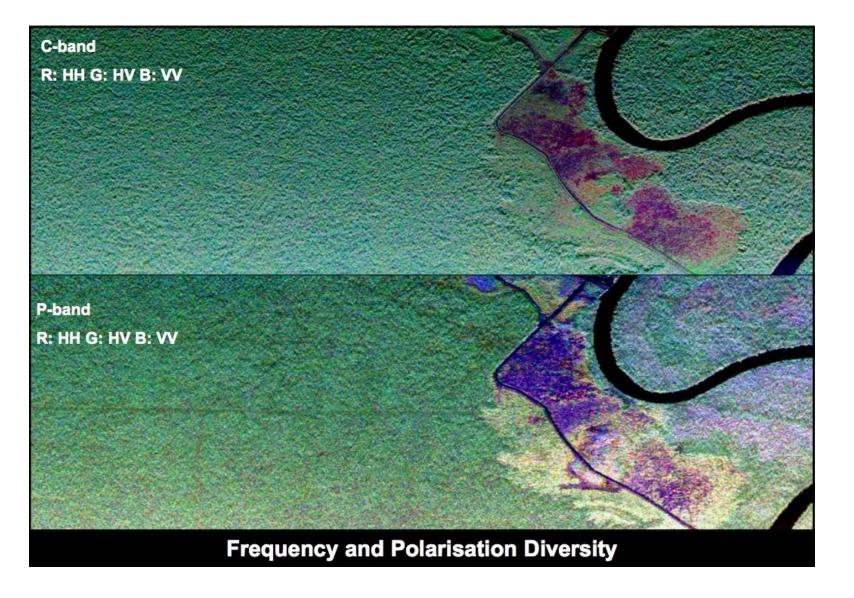
- Waves can penetrate into vegetation and, in dry conditions, soil.
- Generally, the longer the wavelength, the stronger the penetration into the target.

Image Based on ESA Radar Course 2





# Example: RADAR Signal Penetration into Vegetation

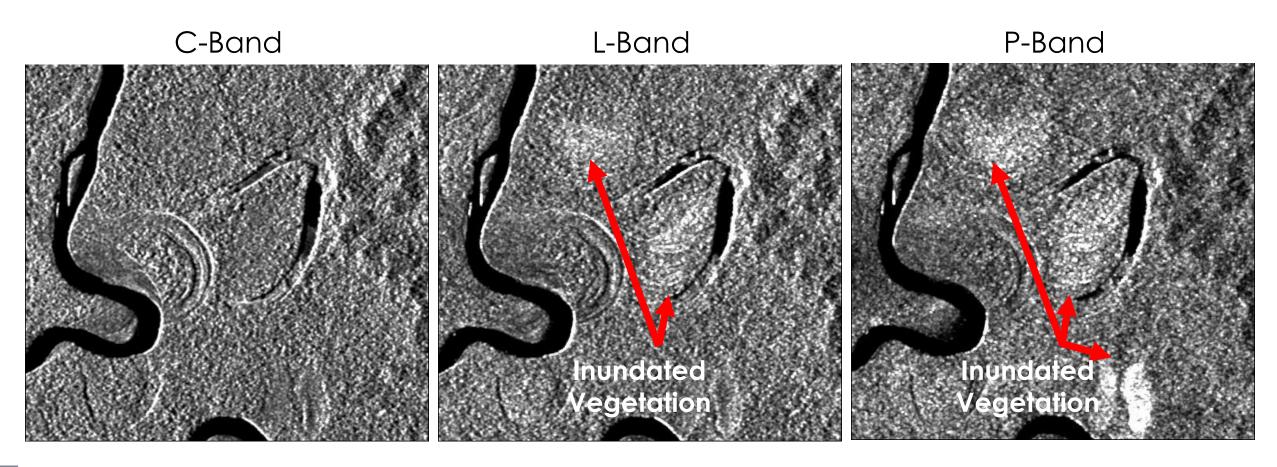




## Example: RADAR Signal Penetration into Vegetation

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Multi-frequency AIRSAR Data over Manu National Park in Peru



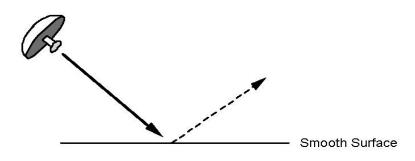


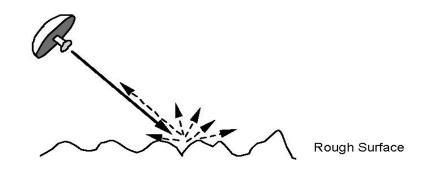
## **RADAR Signal Interaction**

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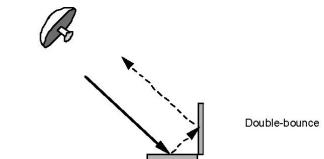
- The RADAR signal is primarily sensitive to surface structure.
- The scale of the objects on the surface relative to the wavelength determine how rough or smooth they appear to the radar signal and how bright or dark they will appear in the image.

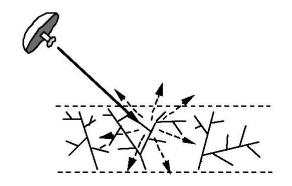
#### **Backscattering Mechanisms**





#### **Backscattering Mechanisms**





Vegetation Layer

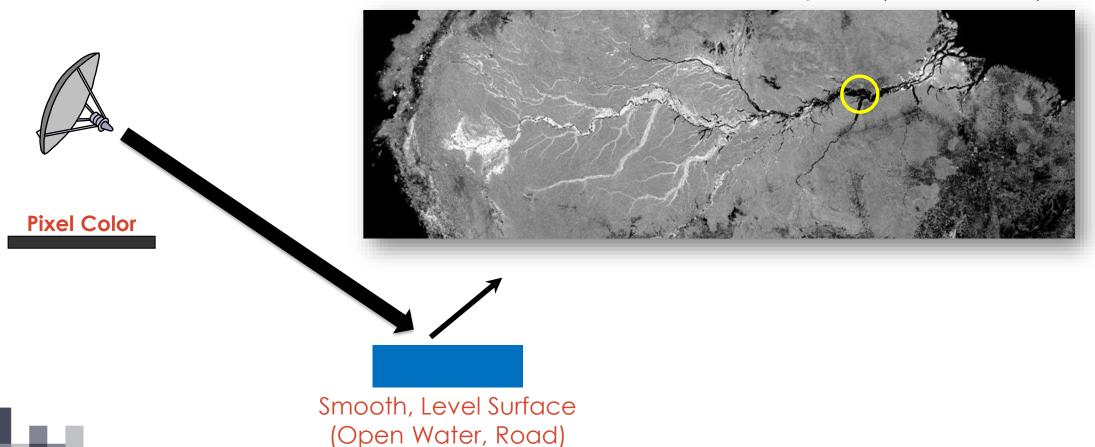


# Examples of RADAR Scattering: Specular Reflection



Smooth Surface Reflection (Specular Reflection)

SMAP RADAR Mosaic of the Amazon Basin - Apr. 2015 (L-band, HH, 3km)



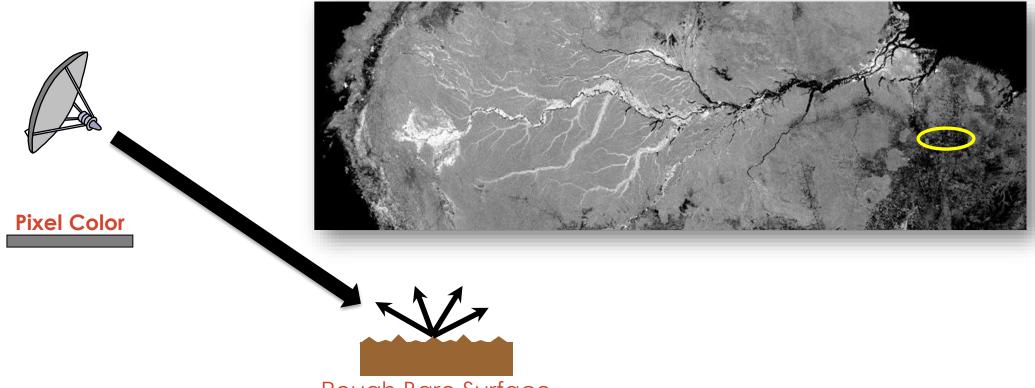


## RADAR Scattering: Rough Surface Reflection



## Rough Surface Reflection

SMAP RADAR Mosaic of the Amazon Basin - Apr. 2015 (L-band, HH, 3km)



Rough Bare Surface (Deforested Areas, Tilled Agricultural Fields)

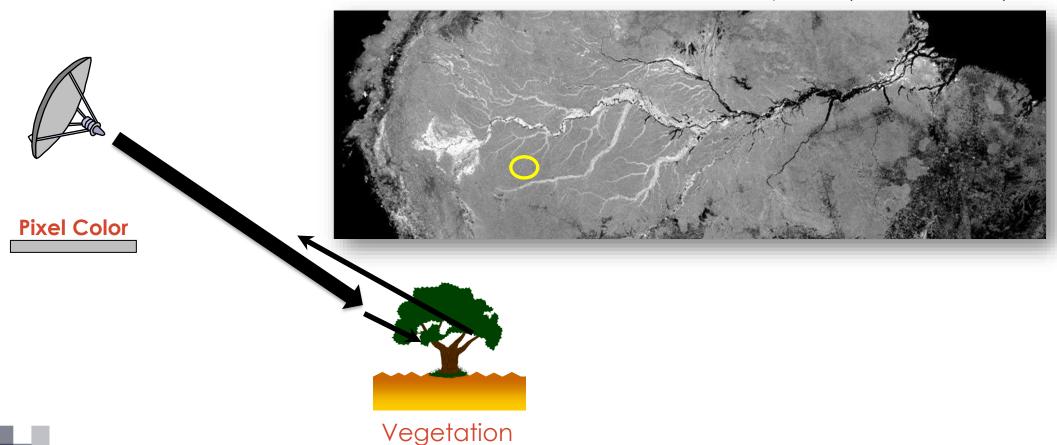


# RADAR Scattering: Volume Scattering



Volume Scattering by Vegetation

SMAP RADAR Mosaic of the Amazon Basin - Apr. 2015 (L-band, HH, 3km)

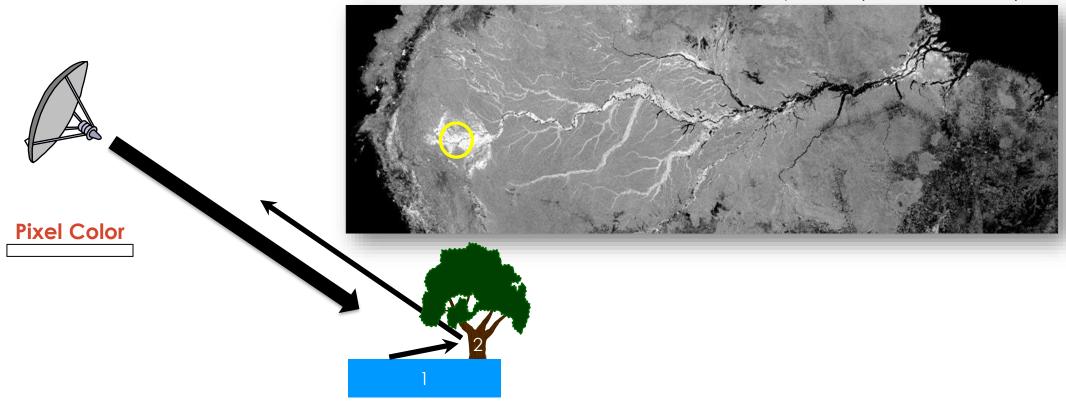


# RADAR Scattering: Double-Bounce



#### Double-Bounce

SMAP RADAR Mosaic of the Amazon Basin - Apr. 2015 (L-band, HH, 3km)



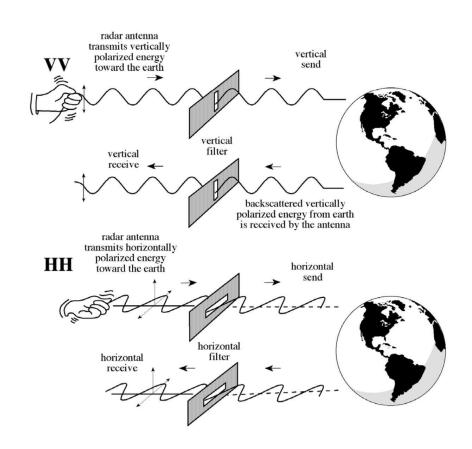
**Inundated Vegetation** 



## **RADAR Parameters: Polarization**

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- The RADAR signal is polarized.
- The polarizations are usually controlled between H and V:
  - HH: Horizontal Transmit, Horizontal Receive
  - HV: Horizontal Transmit, Vertical Receive
  - VH: Vertical Transmit, Horizontal Receive
  - VV: Vertical Transmit, Vertical Receive
- Quad-Pol Mode: When all four polarizations are measured.
- Different polarizations can determine the physical properties of the object observed.

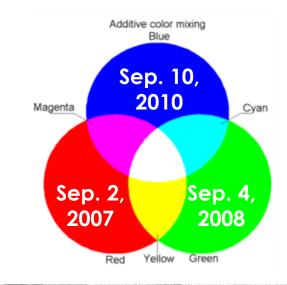




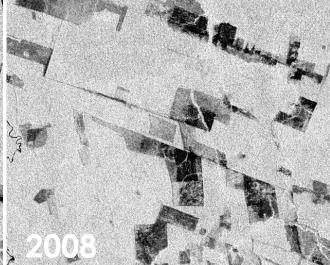
## Visualizing Time Series SAR Data

## PALSAR HV Multi-Temporal RGB for Rondonia, Brazil













## **RADAR Data from Different Satellites**





Legacy:



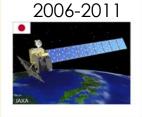
ERS 1/2 1991-2011



**ENVISAT** 2002-2012



ALOS-1 2006-2011



Radarsat-1 1995-2013



Current:

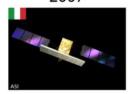


TanDEM-X

Radarsat-2 2007



COSMO-SkyMed 2007



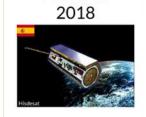
ALOS-2 2014



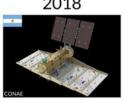
Sentinel-1 2014



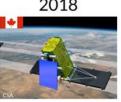
**PAZ SAR** 



SAOCOM 2018



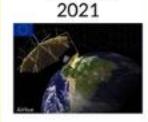
**RCM** 2018



Future:

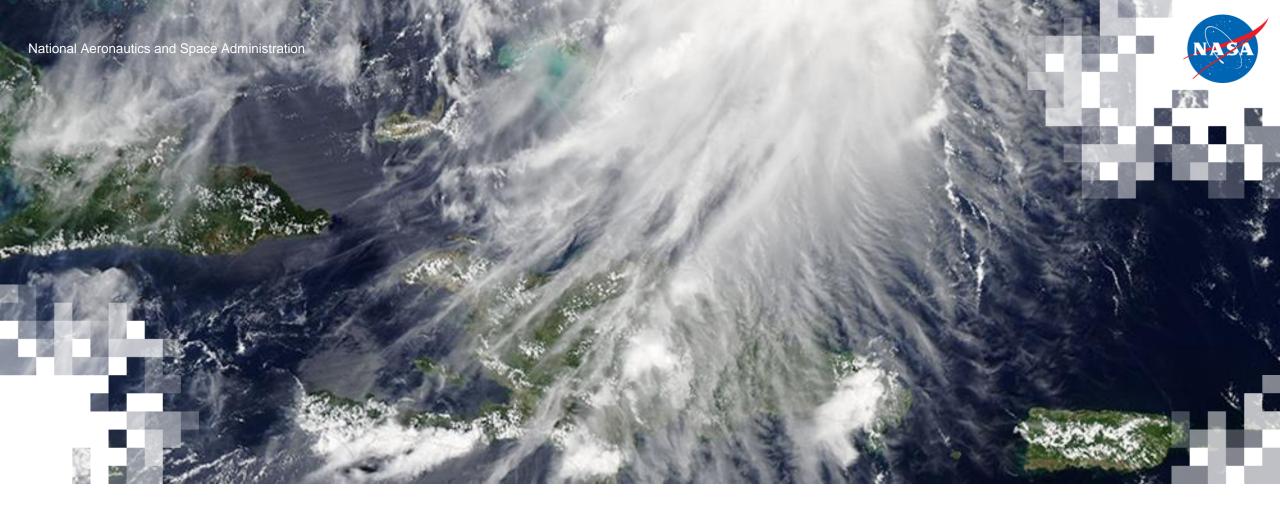


**Biomass** 2021



Credit: Franz Meyer, University of Alaska, Fairbanks







Assessing Flood Extent with SAR and Storm Impacts Using Google Earth Engine

https://code.earthengine.google.com/40ee0214e1183f8c4c21726c28356cc1

Erika Podest & Sean McCartney

#### **Focus Area**

Our demo is focused on floods and storm impacts in Puerto Rico as a result of Hurricane Maria that occurred in Sep. of 2017.

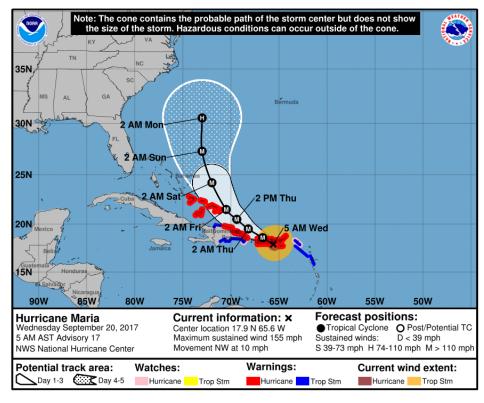




Image Credit: <u>USDA</u>



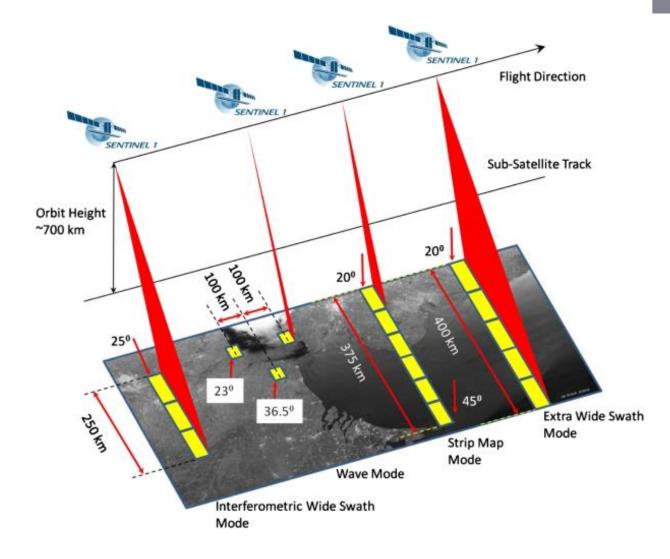


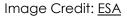
## **Sentinel-1 Data**

# en,

## Two Satellites: A & B

- C-band data
- Each satellite has global coverage every 12 days





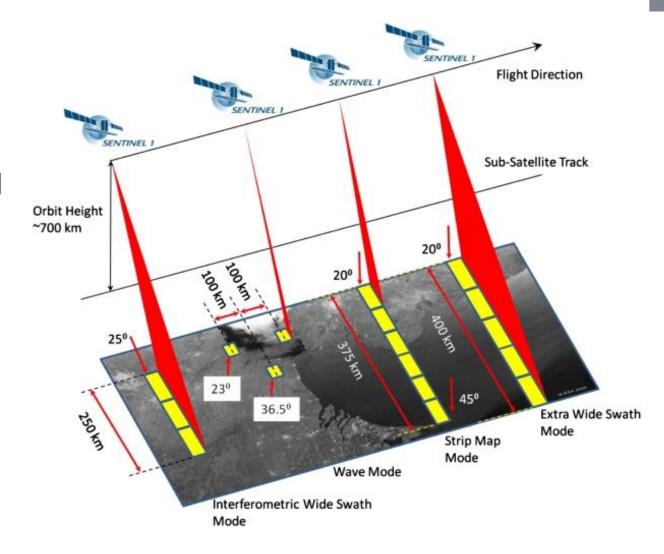


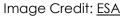
#### **Sentinel-1 Data**



#### **Different Modes:**

- Extra Wide Swath For monitoring oceans and coasts
- Strip Mode By special order only and intended for special needs
- Wave Mode Routine collection for the ocean
- Interferometric Wide Swath Routine collection for land (this is the one you want to use for flood mapping)







## **Sentinel-1 Catalog**

#### https://developers.google.com/earth-engine/datasets/catalog/COPERNICUS\_S1\_GRD

The Sentinel-1 mission provides data from a dual-polarization C-band Synthetic Aperture Radar (SAR) instrument. This collection includes the S1 Ground Range Detected (GRD) scenes, processed using the Sentinel-1 Toolbox to generate a calibrated, ortho-corrected product. The collection is updated weekly.

This collection contains all of the GRD scenes. Each scene has one of 3 resolutions (10, 25 or 40 meters), 4 band combinations (corresponding to scene polarization) and 3 instrument modes. Use of the collection in a mosaic context will likely require filtering down to a homogenous set of bands and parameters. See this article for details of collection use and preprocessing. Each scene contains either 1 or 2 out of 4 possible polarization bands, depending on the instrument's polarization settings. The possible combinations are single band VV or HH, and dual band VV+VH and HH+HV:

- 1. VV: single co-polarization, vertical transmit/vertical receive
- 2. HH: single co-polarization, horizontal transmit/horizontal receive
- 3. VV + VH: dual-band cross-polarization, vertical transmit/horizontal receive
- 4. HH + HV: dual-band cross-polarization, horizontal transmit/vertical receive

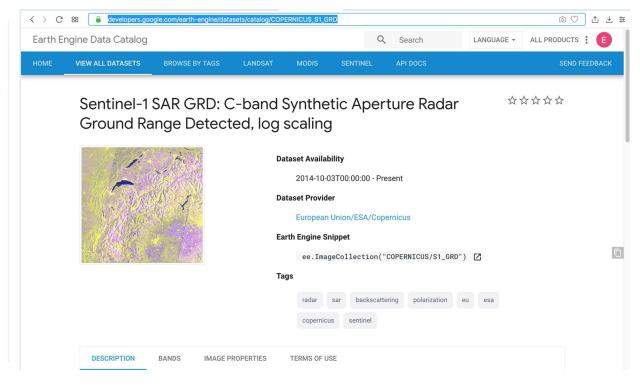
Each scene also includes an additional 'angle' band that contains the approximate viewing incidence angle in degrees at every point. This band is generated by interpolating the 'incidenceAngle' property of the 'geolocationGridPoint' gridded field provided with each asset.

Each scene was pre-processed with Sentinel-1 Toolbox using the following steps:

- 1. Thermal noise removal
- 2. Radiometric calibration
- 3. Terrain correction using SRTM 30 or ASTER DEM for areas greater than 60 degrees latitude, where SRTM is not available. The final terrain-corrected values are converted to decibels via log scaling (10\*log10(x).

For more information about these pre-processing steps, please refer to the Sentinel-1 Pre-processing article.

This collection is computed on-the-fly. If you want to use the underlying collection with raw power values (which is updated faster), see COPERNICUS/S1\_GRD\_FLOAT.





## **Homework and Certificate**

- One homework assignment:
  - Answers must be submitted via Google Form, accessed from the ARSET website.
  - Homework will be made available on August 26<sup>th</sup>.
  - Due date for homework: September 15, 2021
- A certificate of completion will be awarded to those who:
  - Attend all live webinars
  - Complete the homework assignment by the deadline
  - You will receive a certificate approximately two months after the completion of the course from: marines.martins@ssaihq.com



## Contacts



#### Trainers:

- Erika Podest: <u>erika.podest@jpl.nasa.gov</u>
- Sean McCartney: <a href="mailto:sean.mccartney@nasa.gov">sean.mccartney@nasa.gov</a>
- Amita Mehta: <u>amita.v.mehta@nasa.gov</u>

# Follow us on Twitter @NASAARSET

## Training Webpage:

 https://appliedsciences.nasa.gov/join-mission/training/english/arsetsatellite-observations-analyzing-natural-hazards-small-island

#### **ARSET Website:**

 https://appliedsciences.nasa.gov/what-we-do/capacitybuilding/arset



## **Questions**

- Please enter your questions in the Q&A box. We will answer them in the order they were received.
- We will post the Q&A to the training website following the conclusion of the webinar.

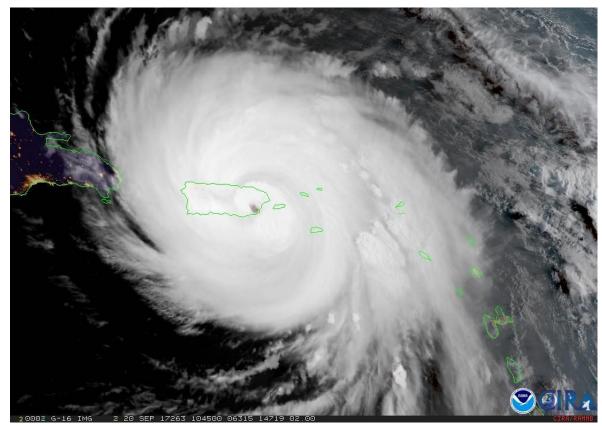


Image Credit: NOAA

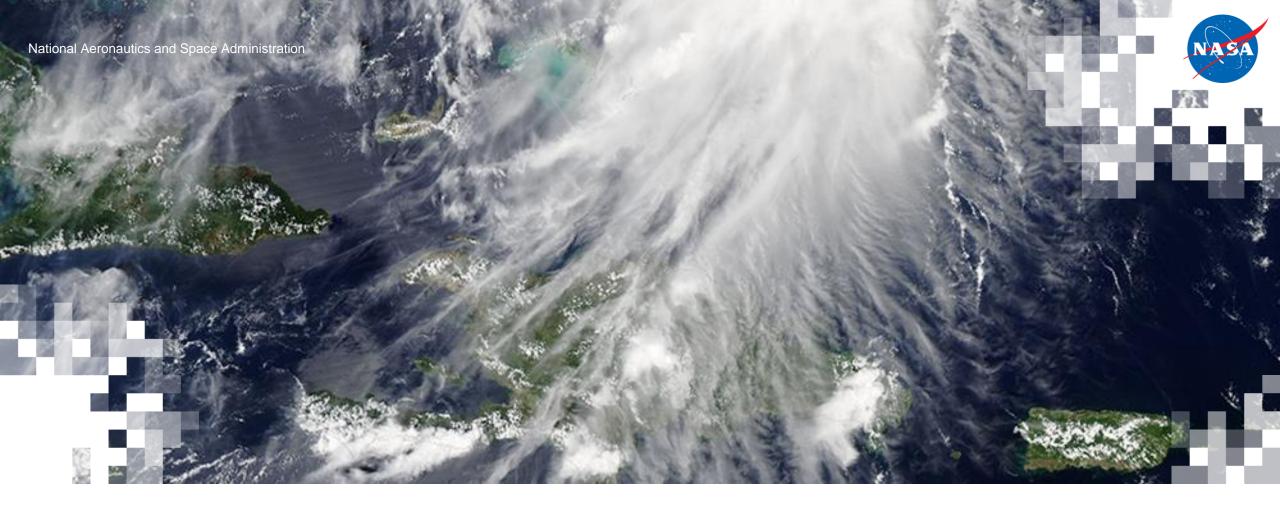






## **Thank You!**







Appendix

# Weather, Climate, and Hydrology Data



Parameter	Satellite/Model	Sensors	Spatial/Temporal Resolutions and Coverage
Rainfall	Combined TRMM & GPM  With Multiple Satellite  Constellation  IMERG	Microwave Radiometer (TMI, GMI) and RADAR (PR, DPR)  Microwave Imagers and Sounders Calibrated with GPM Sensor Data	0.1° x 0.1° 30-minute, Daily, Monthly 6/2000 to present
Sea Level Pressure, Winds	MERRA-2	-	0.5° x 0.667°, Hourly, Monthly 1980 to Present
Sea Level Pressure, Winds, Rainfall		<del>-</del>	0.3125°x0.25° Hourly, Near-real Time and 5-day Forecast

TRMM: Tropical Rainfall Measurement Mission

IMERG: The Integrated Multi-satellitE Retrievals for GPM

MERRA-2:Modern-Era Retrospective analysis for Research and Applications, Version 2 GOES-5 FP: Goddard Earth Observing System, Version 5 (GEOS-5) Forward Processing

GPM: Global Precipitation Measurement



## Weather, Climate, and Hydrology Data

Parameter	Model	Spatial/Temporal Resolutions and Coverage
Precipitation, Temperature, Relative Humidity, Winds	MERRA-2	0.5° x 0.667°, Hourly, Monthly 1980 to Present
Precipitation, Temperature, Relative Humidity, Winds	GEOS-5 FP	0.3125°x0.25° Hourly, Near-real Time and 5-day Forecast
Soil Moisture	NLDAS	0.125° x 0.125°, Hourly, Monthly 1979 to Present
	GLDAS v2.1	0.25° x 0.25°, 1° x 1°, 3-hourly, Monthly 2000 to Present

MERRA-2:Modern-Era Retrospective analysis for Research and Applications, Version 2 <a href="https://gmao.gsfc.nasa.gov/reanalysis/MERRA-2/index.php">https://gmao.gsfc.nasa.gov/reanalysis/MERRA-2/index.php</a>

GOES-5 FP: Goddard Earth Observing System, Version 5 (GEOS-5) Forward Processing <a href="https://gmao.gsfc.nasa.gov/weather-prediction/">https://gmao.gsfc.nasa.gov/weather-prediction/</a>

NLDAS: North American Land Data Assimilation System <a href="https://ldas.gsfc.nasa.gov/nldas">https://ldas.gsfc.nasa.gov/nldas</a>

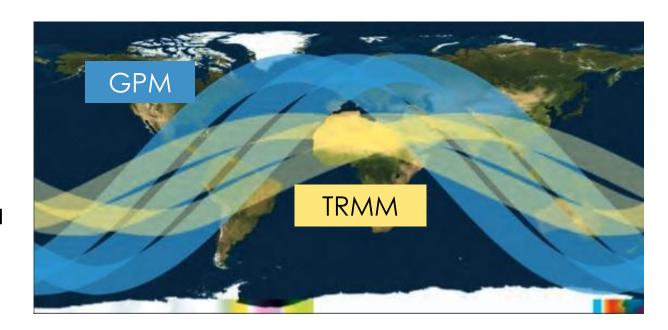
GLDAS: Global Land Data Assimilation System <a href="https://ldas.gsfc.nasa.gov/gldas">https://ldas.gsfc.nasa.gov/gldas</a>



# Global Precipitation Measurement (GPM) Mission

## http://pmm.nasa.gov/GPM/

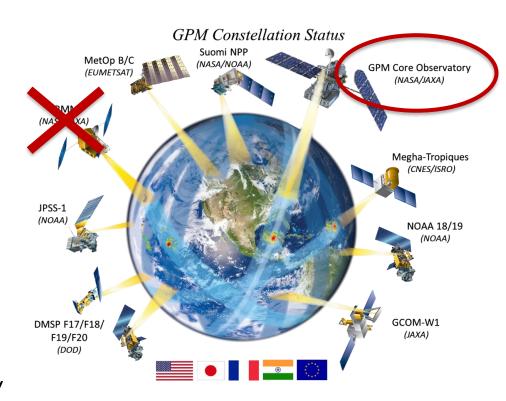
- Core satellite launched Feb 27, 2014
  - Non-Polar, Low-Inclination Orbit
    - Altitude: 407 km
- Spatial Coverage:
  - 16 orbits a day, covering global area between 65°S and 65°N
- Along with a constellation of satellites, GPM has a revisit time of 2-4 hrs. over land.
- Sensors:
  - GMI (GPM Microwave Imager)
  - DPR (Dual Precipitation Radar)



Global Precipitation Measurement (GPM) Mission & Tropical Rainfall Measurement Mission (TRMM)

#### **IMERG Version 06 Data**

- IMERG is a single integrated code system for near-real and post-real time.
- Multiple runs for different user requirements for latency and accuracy
  - "Early" 4 hr. (flash flooding)
  - "Late" 14 hr. (crop forecasting)
  - "Final" 3 months (research)
- Morphing of precipitation based on numerical models poleward of 60° N/S latitude
- Overall calibration is provided by TRMM and GPM Combined Radar-Radiometer Algorithm. TRMM June 2000-May 2014, GPM thereafter.
- IMERG is adjusted to GPCP monthly climatology zonally to achieve a bias profile that is considered reasonable.







# NASA Earth System Model Forecast (GEOS-5)

https://gmao.gsfc.nasa.gov/GEOS\_systems/

- Goddard Earth Observing System (GEOS)-5 provides near real-time data and forecast data
- Data available at 5/16 x 1/4-degree long-lat grid, 42 vertical level
- Surface data available every hour
- Atmospheric (A), Oceanic (O), and Coupled A-O General Circulation Model configuration options
- Chemistry-Climate and Chemistry-Transport models available

#### **Weather Maps**

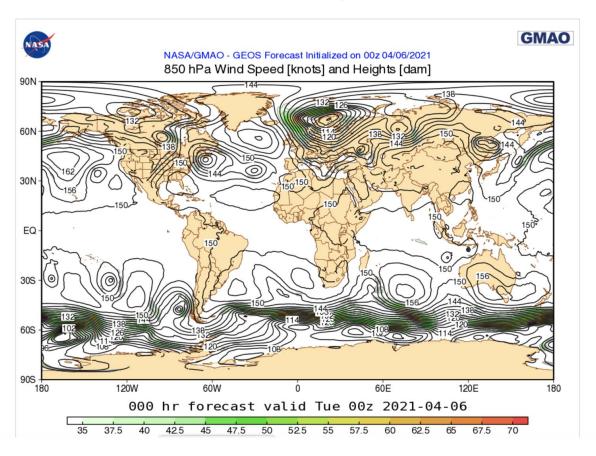


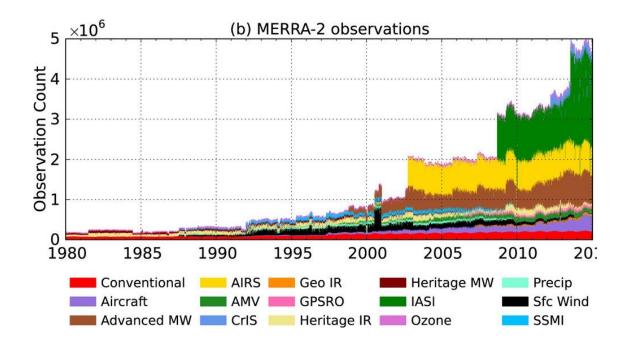
Image Credit: NASA GMAO



#### MERRA-2

#### https://gmao.gsfc.nasa.gov/reanalysis/MERRA-2/

- Blends the vast quantities of observational data with output data from the Goddard Earth Observing System (GEOS-5) model (1980 – present)
- Provides state-of-the-art global analyses on weather to climate time scales
- Focuses on improvement in the hydrological cycle



MERRA-2 Overview: <u>The Modern-Era Retrospective Analysis for Research and Applications, Version 2 (MERRA-2)</u>, Ronald Gelaro, et al., 2017, J. Clim., <u>doi: 10.1175/JCLI-D-16-0758.1</u>



# Additional Google Earth Engine Code



- Total Precipitation from Hurricane Maria: https://code.earthengine.google.com/3376a412623fee73bd0be6275b97f87c
- Time Series: https://code.earthengine.google.com/f0885054cbd03886f204f189473d5ea5
- Animation: https://code.earthengine.google.com/1d8ff136c8c7a0093cc51fc771519e5a
- Flood Extent & Impact: https://code.earthengine.google.com/6d7b34248dc7631ec1fdb063fee7c6ad

